CHAPTER 6

Hearing Protectors

A personal hearing protection device (or hearing protector) is any device designed to reduce the level of sound reaching the eardrum. Earmuffs, earplugs, and ear canal caps (also called semi-inserts) are the main types of hearing protectors. A wide range of hearing protectors exists within each of these categories. For example, earplugs may be subcategorized into foam, user-formable (such as silicon or spun mineral fiber), premolded, and custom-molded earplugs. In addition, some types of helmets (in particular, flight helmets worn in the military) also function as hearing protectors. Refer to Nixon and Berger [1991] for a detailed discussion of the uses, advantages, and disadvantages of each type of protector. Items not specifically designed to serve as hearing protectors (e.g., cigarette filters, cotton, and .38-caliber shells) should not be used in place of hearing protectors. Likewise, devices such as hearing aid earmolds, swim molds, and personal stereo earphones must never be considered as being hearing protective.

Ideally, the most effective way to prevent NIHL is to remove the hazardous noise from the workplace or to remove the worker from the hazardous noise. Hearing protectors should be used when engineering controls and work practices are not feasible for reducing noise exposures to safe levels. In some cases, hearing protectors are an interim solution to noise exposure. In other instances, hearing protectors may be the only feasible means of protecting the worker. When a worker's time-weighted noise exposure exceeds 100 dBA, both earplugs and earmuffs should be worn. It is important to note that using such double protection will add only 5 to 10 dB of attenuation [Nixon and Berger 1991]. Given the real-world performance of hearing protectors [Berger et al. 1996], NIOSH cautions that even double protection is inadequate when TWA exposures exceed 105 dBA.

How much attenuation a hearing protector provides depends on its characteristics and how the worker wears it. The selected hearing protector must be capable of keeping the noise exposure at the ear below 85 dBA. Because a worker may not know how long a given noise exposure will last or what additional noise exposure he or she may incur later in the day, it may be prudent to wear hearing protectors whenever working in hazardous noise. Workers and supervisors should periodically ensure that the hearing protectors are worn correctly, are fitted properly, and are appropriate for the noise in which they are worn [Helmkamp et al. 1984; Gasaway 1985; Berger 1986; Royster and Royster 1990; NIOSH 1996].

Historically, emphasis has been placed on a hearing protector's attenuation characteristics—almost to the exclusion of other qualities necessary for it to be effective. Although those who select hearing protectors should consider the noise in which they will be worn, they must also consider the workers who will be wearing them, the need for compatibility with other safety equipment, and workplace conditions such as temperature, humidity, and atmospheric pressure [Gasaway 1985; Berger 1986]. In addition, a variety of styles should be provided so that workers may select a hearing protector on the basis of comfort, ease of use and handling, and impact on communication [NIOSH 1996; Royster and Royster 1990]. Each worker should receive individual training in the selection, fitting, use, repair, and replacement of the hearing protector [Gasaway 1985; Royster and Royster 1990; NIOSH 1996]. What is the best hearing protector for some workers may not be the best for others [Casali and Park 1990]. The most common excuses reported by workers for not wearing hearing protectors include discomfort, interference with hearing speech and warning signals, and the belief that workers have no control over an inevitable process that culminates in hearing loss [Berger 1980; Helmkamp 1986; Lusk et al. 1993]. Fortunately, none of these reasons present insurmountable barriers. Given adequate education and training, each can be successfully addressed [Lusk et al. 1995; Merry 1996; Stephenson 1996].

Workers and management must recognize the crucial importance of wearing hearing protectors correctly. Intermittent wear will dramatically reduce their effective protection [NIOSH 1996]. For example, a hearing protector that could optimally provide 30 dB of attenuation for an 8-hr exposure would effectively provide only 15 dB if the worker removed the device for a cumulative 30 min during an 8-hr day. *The best hearing protector is the one that the worker will wear.*

Several methods exist for estimating the amount of sound attenuation a hearing protector provides. In the United States, the NRR is required by law [40 CFR 211] to be shown on the label of each hearing protector sold. The NRR was designed to function as a simplified descriptor of the amount of protection provided by a given device. When its use was first proposed, the most typical method used to characterize sound attenuation was the real ear attenuation at threshold (REAT) method, as described in ANSI S3.19–1974 [ANSI 1974]. Sometimes called the octave-band or long method, this method was believed to provide too much information to be useful for labeling purposes; thus a single-number descriptor (NRR) was devised.

The formulas used to calculate the NRR are based on the octave-band, experimenter fit, REAT method. The NRR was intended to be used to calculate the exposure under the hearing protector by subtracting the NRR from the *C-weighted* unprotected noise level. It is important to note that when working with A-weighted noise levels, one must subtract an additional 7 dB from the labeled NRR to obtain an estimate of the A-weighted noise level under the protector. OSHA has prescribed six methods* with which the NRR can be used. (See 29 CFR 1910.95, Appendix B, and descriptions of methods for calculating and using the NRR in *The NIOSH Compendium of Hearing Protection Devices* [NIOSH 1994].)

*The OSHA methods are a simplification of NIOSH methods #2 and #3 [NIOSH 1975, 1994; Lempert 1984].

One problem inherent to using single-number descriptors of sound attenuation is the need to ensure that the resulting value does not sacrifice the estimated protection for the sake of simplicity. Thus these calculations will typically *underestimate* laboratory-derived "long methods" for estimating sound attenuation. To get around some of the limitations associated with NRR calculations, other methods have been developed for estimating hearing protector performance. The single-number rating method and the high-middle-low method may be used when a person needs to estimate performance more accurately than possible with the NRR but does not want to resort to octave-band descriptions of sound attenuation. Detailed descriptions of these methods are in *The NIOSH Compendium of Hearing Protection Devices* [NIOSH 1994].

Both NRR and the other hearing protector ratings referred to above are based on data obtained under laboratory conditions in which experimenters fit hearing protectors on trained listeners. As such, these ratings may differ markedly from the noise reduction that a worker would actually experience in the real world. Specifically, studies have repeatedly demonstrated that real-world protection is substantially less than noise attenuation values derived from experimenter-fit, laboratory-based methods. In the late 1970's and early 1980's, two NIOSH field studies found that insert-type hearing protectors in the field provided less than half the noise attenuation measured in the laboratory [Edwards et al. 1979; Lempert and Edwards 1983]. Since the 1970's, additional studies have been conducted on real-world noise attenuation with hearing protectors [Regan 1975; Padilla 1976; Abel et al. 1978; Edwards et al. 1978; Fleming 1980; Crawford and Nozza 1981; Chung et al. 1983; Hachey and Roberts 1983; Royster et al. 1984; Behar 1985; Mendez et al. 1986; Smoorenburg et al. 1986; Edwards and Green 1987; Pekkarinen 1987; Pfeiffer et al. 1989; Hempstock and Hill 1990; Berger and Kieper 1991; Casali and Park 1991; Durkt 1993]. In general, these studies involved testing the hearing thresholds of occluded and unoccluded ears of subjects who wore the hearing protectors for the test in the same manner as on the job. The tests attempted to simulate the actual conditions in which hearing protectors are normally used in the workplace. Table 6–1 compares the NRRs derived from these real-world noise attenuation data with the manufacturers' labeled NRRs or laboratory NRRs. The laboratory NRRs consistently overestimated the real-world NRRs by 140% to 2,000% [Berger et al. 1996]. In general, the data show that earmuffs provide the highest real-world noise attenuation values, followed by foam earplugs; all other insert-type devices provide the least attenuation. From these results, it can also be concluded that ideally, workers should be individually fit-tested for hearing protectors. Currently, several laboratories are exploring feasible methods for this type of fit testing [Michael 1997].

Royster et al. [1996] addressed problems associated with the use of the NRR. These researchers demonstrated that relying on the manufacturer's instructions or the experimenter to fit hearing protectors may be of little value in estimating the protection a worker obtains under conditions of actual use. The Royster et al. [1996] study reported the results of an interlaboratory investigation of methods for assessing hearing protector performance. The results demonstrated that using untrained subjects to fit their hearing protectors provided much better estimates of the hearing protector's noise attenuation in the workplace than using the experimenter to fit them. This method has since been adopted for use by ANSI in ANSI S12.6–1997 [ANSI 1997]. Furthermore, the method has subsequently been endorsed by the NHCA Task Force on Hearing Protector Effectiveness as well as numerous other professional organizations.†

OSHA [1983] has instructed its compliance officers to derate the NRR by 50% in enforcing the engineering control provision of the OSHA noise standard. However, NIOSH concurs with the professional organizations cited above and recommends using subject fit data based on ANSI S12.6–1997 [ANSI 1997] to estimate hearing protector noise attenuation. If subject fit data are not available, NIOSH recommends derating hearing protectors by a factor that corresponds to the available real-world data. Specifically, NIOSH recommends that the labeled NRRs be derated as follows:

Earmuffs	Subtract 25% from the manufacturer's labeled NRR
Formable earplugs	Subtract 50% from the manufacturer's labeled NRR
All other earplugs	Subtract 70% from the manufacturer's labeled NRR

For example, measure noise exposure levels in dBC or dBA with a sound level meter or noise dosimeter.

1. When the noise exposure level in dBC is known, the effective A-weighted noise level (ENL) is:

$$\text{ENL} = \text{dBC} - \text{derated NRR}$$

2. When the noise exposure level in dBA is known, the effective A-weighted noise level is:

$$\text{ENL} = \text{dBA} - (\text{derated NRR} - 7)$$

To summarize, the best hearing protection for any worker is the removal of hazardous noise from the workplace. Until that happens, the best hearing protector for a worker is the one he or she will wear willingly and consistently. The following factors are extremely important determinants of worker acceptance of hearing protectors and the likelihood that workers will wear them consistently:

- Convenience and availability
- Belief that the device can be worn correctly
- Belief that the device will prevent hearing loss
- Belief that the device will not impair a worker's ability to hear important sounds
- Comfort
- Adequate noise reduction
- Ease of fit
- Compatibility with other personal protective equipment

†The following organizations have endorsed the use of the subject fit procedure according to ANSI S12.6: Acoustical Society of America, American Academy of Audiology, American Association of Occupational Health Nurses, American Industrial Hygiene Association (AIHA), American Society of Safety Engineers, ASHA, CAOHC, and NHCA.

Table 6–1. Summary of real-world NRRs achieved by 84% of the wearers of hearing protectors in 20 independent studies*

Type of hearing protector, model, and reference	Test population (number)	Labeled NRR†	NRR84	Weighted mean NRR84‡	Mean NRR84
Foam:					
E-A-R	—	—	—	12.5	13.2
Crawford and Nozza [1981]	58	29	19	—	—
Hachey and Roberts [1983]	31	29	9	—	—
Lempert and Edwards [1983]	56	29	12	—	—
Edwards and Green [1987]	28	29	19	—	—
Edwards and Green [1987]	28	29	14	—	—
Lempert and Edwards [1983]	56	29	5	—	—
Abel et al. [1978]	55	29	9	—	—
Abel et al. [1978]	24	29	9	—	—
Behar [1985]	42	29	14	—	—
Behar [1985]	24	29	16	—	—
Pfeiffer et al. [1989]	69	29	10	—	—
Casali and Park [1991]	10	29	6	—	—
Casali and Park [1991]	10	29	23	—	—
Hempstock and Hill [1990]	72	29	13	—	—
Berger and Kieper [1991]	22	29	20	—	—
Premolded:					
Ultra-Fit	—	—	—	5.8	7.3
Casali and Park [1991]	10	21	4	—	—
Casali and Park [1991]	10	21	17	—	—
Royster et al. [1984]	19	21	5	—	—
Berger and Kieper [1991]	29	21	3	—	—
V–51R	—	—	—	0.1	2.2
Royster et al. [1984]	12	23	3	—	—
Abel et al. [1978]	20	23	2	—	—
Edwards et al. [1978]	84	23	1	—	—
Fleming [1980]	9	23	6	—	—
Padilla [1976]	183	23	-1	—	—

See footnotes at end of table.

(Continued)

Table 6–1 (Continued). Summary of real-world NRRs achieved by 84% of the wearers of hearing protectors in 20 independent studies*

Type of hearing protector, model, and reference	Test population (number)	Labeled NRR†	NRR84	Weighted mean NRR84‡	Mean NRR84
Premolded (Continued):					
Accu-Fit or Com-Fit	—	—	—	4.9	4.5
Fleming [1980]	13	26	2	—	—
Abel et al. [1978]	18	26	7	—	—
EP100	—	—	—	2.1	1.5
Crawford and Nozza [1981]	22	26	0	—	—
Edwards et al. [1978]	28	26	-2	—	—
Abel et al. [1978]	45	26	10	—	—
Smoorenburg et al. [1986]	46	26	-2	—	—
NA	—	—	—	1.0	1.0
Regan [1975]	30	NA	1	—	—
Fiberglass:					
Down	—	—	—	3.3	3.5
Lempert and Edwards [1983]	28	15	4	—	—
Edwards et al. [1978]	56	15	3	—	—
POP	—	—	—	7.7	7.8
Lempert and Edwards [1983]	28	22	4	—	—
Behar [1985]	28	22	10	—	—
Pfeiffer et al. [1989]	51	22	7	—	—
Regan [1975]	30	22	10	—	—
Hempstock and Hill [1990]	39	22	8	—	—
Soft	—	—	—	3.4	4.7
Hachey and Roberts [1983]	36	26	1	—	—
Pfeiffer et al. [1989]	12	26	9	—	—
Hempstock and Hill [1990]	32	26	4	—	—
Custom	—	—	—	6.5	5.4
Adcosil:					
Hachey and Roberts [1983]	44	24	4	—	—
NA:					
Crawford and Nozza [1981]	7	NA	7	—	—
Prtctear/vent:					
Lempert and Edwards [1983]	56	11	8	—	—
Peacekeeper:					
Lempert and Edwards [1983]	56	15	4	—	—

See footnotes at end of table.

(Continued)

Table 6–1 (Continued). Summary of real-world NRRs achieved by 84% of the wearers of hearing protectors in 20 independent studies*

Type of hearing protector, model, and reference	Test population (number)	Labeled NRR†	NRR84	Weighted mean NRR84‡	Mean NRR84
Custom (Continued):					
NA:					
Abel et al. [1978]	48	NA	3	—	—
Regan [1975]	6	NA	4	—	—
Padilla [1976]	230	NA	8	—	—
Semiaural:					
Sound-Ban	—	—	—	9.6	9.3
Behar [1985]	32	17	10	—	—
Casali and Park [1991]	10	19	6	—	—
Casali and Park [1991]	10	19	12	—	—
Earmuffs	—	—	—	13.8	13.8
Bilsom UF–1:					
Hachey and Roberts [1983]	31	25	13	—	—
Casali and Park [1991]	10	25	16	—	—
Casali and Park [1991]	10	25	20	—	—
MSA Mark IV:					
Abel et al. [1978]	47	23	11	—	—
Durkt [1993]	15	23	4	—	—
Optac 4000:					
Pfeiffer et al. [1989]	33	NA	14	—	—
Peltor H9A:					
Pfeiffer et al. [1989]	34	22	14	—	—
Rcal Auralguard III:					
Hempstock and Hill [1990]	42	NA	19	—	—
Norseg:					
Regan [1975]	30	NA	8	—	—
AO 1720:					
Durkt [1993]	11	21	6	—	—
Bilsom 2450:					
Pfeiffer et al. [1989]	11	NA	13	—	—
Clark E805:					
Abel et al. [1978]	17	23	15	—	—
Glendale 900:					
Durkt [1993]	10	21	10	—	—
Optac 4000S:					
Pfeiffer et al. [1989]	10	NA	14	—	—

See footnotes at end of table.

(Continued)

Table 6–1 (Continued). Summary of real-world NRRs achieved by 84% of the wearers of hearing protectors in 20 independent studies*

Type of hearing protector, model, and reference	Test population (number)	Labeled NRR†	NRR84	Weighted mean NRR84‡	Mean NRR84
Earmuffs (Continued):					
Safety 208:					
Abel et al. [1978]	15	22	12	—	—
Safety 204:					
Behar [1985]	9	21	22	—	—
Welsh 4530:					
Regan [1975]	5	25	20	—	—
Miscellaneous:					
Pekkarinen [1987]	71	NA	13	—	—
Safir E/ISF:					
Hempstock and Hill [1990]	20	NA	14	—	—
Miscellaneous:					
Chung et al. [1983]	64	24	18	—	—
Cap Muffs	—	—	—	14.3	14.8
Bilsom 2313:					
Hempstock and Hill [1990]	37	23	16	—	—
Hellberg No Noise:					
Abel et al. [1978]	58	23	11	—	—
Peltor H7P3E:					
Behar [1985]	36	24	13	—	—
AO 1776K:					
Behar [1985]	26	21	14	—	—
Hellberg 26007:					
Hempstock and Hill [1990]	20	NA	18	—	—
Miscellaneous:					
Chung et al. [1983]	37	23	17	—	—
Plug+Muff:					
E-A-R + UF–1:					
Hachey and Roberts [1983]	10	—	25	25.0	25.0

*Adapted from Berger et al. [1996].
†Abbreviations: NRR = noise reduction rating; NRR84 = NRR achieved by 84% of the wearers of hearing protectors; NA = not available.
‡Weighted on the basis of the test population size.

CHAPTER 7

Research Needs

Considerable progress has been made in our understanding of occupational hearing loss prevention. However, additional research is needed to clarify the risks associated with various noise and ototoxic exposures and to reduce the incidence of hearing loss among workers. Furthermore, investigations of possible biological indicators of susceptibility to NIHL would be welcome. For example, although tinnitus is a frequent complaint of the noise-exposed worker, its relationship to permanent hearing loss is not well understood. The additional topics listed in the sections below do not include all areas that would benefit from further investigations, but they represent persistent problems or emerging trends.

7.1 Noise Control

Research is needed to reduce noise exposures through engineering controls in workplaces where the noise exposures are still being controlled primarily by hearing protectors. An HLPP is complex and difficult to manage effectively, and the need for one can be obviated by noise control procedures that reduce noise levels to less than 85 dBA. As important as such noise reduction technologies are, it is equally important to apply traditional noise control engineering concepts to the building of new facilities and equipment. Research also is needed to improve the retrofitting of noise controls to existing operations. A database of effective solutions (best practices) should be created and made accessible to the public.

7.2 Impulsive Noise

Research is needed to define the hazardous parameters of impulsive noise and their interrelationships. These parameters should include amplitude, duration, rise time, number of impulses, repetition rate, and crest factor. In the absence of any other option, impulsive noise is integrated with continuous noise to determine the hazard. Laboratory research with animals and retrospective studies of workers indicate that impulsive noise is more hazardous to hearing than continuous noise of the same spectrum and intensity. However, sufficient data are not available to support the development of damage risk criteria for impulsive noises.

7.3 Nonauditory Effects

Research is needed to define dose-response relationships between noise and nonauditory effects such as hypertension and psychological stress. Studies of hypertension conducted on noise-exposed workers have established a relationship between hypertension and NIHL but have not established a relationship between noise exposure and hypertension. Workplace accidents need to be analyzed to determine whether noise interference with oral communication or audio alarms has been a contributing factor. Technologies must be developed to allow easy identification of warning signals and efficient communication in noisy environments while providing effective hearing protection.

7.4 Auditory Effects of Ototoxic Chemical Exposures

The ototoxic properties of industrial chemicals and their interaction with noise have been investigated for only a few substances. Research in animals is needed to investigate the range of chemicals known to be ototoxic or neurotoxic and to appraise the risk of hearing loss from exposures to these chemicals alone or in combination with noise. Research is needed to support damage risk criteria for combined exposure.

7.5 Exposure Monitoring

NIOSH has been a pioneer in developing an exposure monitoring strategy for air contaminants based on the application of statistical methods [NIOSH 1977]. However, the appropriateness of the strategy for occupational noise exposure has not been determined, and not much research has been conducted in this area since 1977. Limited studies have indicated that a different strategy for monitoring occupational noise exposure may be required [Behar and Plenar 1984; Henry 1992]. Worker exposures to noise must be accurately monitored and appropriate control measures must be implemented when necessary. Several individuals and organizations have proposed different approaches to monitoring noise exposures [Behar and Plenar 1984; CSA 1986; Royster et al. 1986; Hawkins et al. 1991; Henry 1992; Simpson and Berninger 1992; Stephenson 1995]. NIOSH acknowledges the contributions of these individuals and organizations to this important subject and encourages continued effort in the development of exposure monitoring strategies applicable to occupational noise exposure. An important component of HearSaf 2000 is being codeveloped by NIOSH, the United Auto Workers-Ford National Joint Committee on Health and Safety, Hawkwa Group, and James, Anderson and Associates: noise monitoring with emphasis on noise exposure characterizations based on the principles of a task-based exposure assessment model (T-BEAM). The T-BEAM approach stresses the identification of all hazards (including noise) that may be associated with a particular work task. This approach may be especially suitable for mobile or itinerant workers. Additional research is needed to compare these monitoring approaches (including T-BEAM) to determine the best technique for a particular type of worker or work environment.

7.6 Hearing Protectors

The noise attenuation of hearing protectors as they are worn in the occupational environment is usually quite different from that realized in the laboratory. The manufacturer's labeled NRRs (which are currently used by OSHA in determining compliance with the PEL when engineering controls are being implemented or are not feasible) usually do not reflect actual experiences. Thus a pressing need exists for a laboratory method to estimate the noise attenuation obtained with hearing protectors worn in the field. Field research is now needed to validate the new laboratory subject-fit method with onsite fit-testing methods. Research should also lead to the development of hearing protectors that eliminate troublesome barriers by providing increased comfort to wearers as well as improved speech intelligibility and audibility of warning signals. In addition, as new technologies such as active-level dependency and active noise reduction are introduced into personal hearing protection, methods must be developed to describe the effectiveness of these methods alone and when built into passive hearing protectors.

7.7 Training and Motivation

Research is needed in using behavioral survey tools as resources for developing training and education programs that address workers' beliefs, attitudes, and intentions about hearing loss prevention. To date, research in training and motivation has focused on materials and their delivery, with the worker considered the passive receptacle. Research is needed to develop materials and programs that more fully involve the worker in the process and give the worker ownership in the HLPP. Additional methods are also needed to improve the training and motivation of workers who must depend on hearing protection.

7.8 Program Evaluation

Several methods for evaluating the effectiveness of an HLPP are discussed in Chapter 5. No single method is generally accepted as being superior to the rest. Further research and development of methods for evaluating the effectiveness of HLPPs are needed, and the method deemed to have the best balance between accuracy and ease of use should be adopted. All existing methods rely on the results of audiometric testing for evaluating effectiveness of the HLPP. Although audiometric data are crucial for managing an HLPP and evaluating the status of each worker, too much time must pass to build a database of audiograms that can support queries about overall program effectiveness. Methods that do not rely on serial audiograms need to be considered for immediate assessment of program effectiveness. Examples of such methods are observed behaviors that predict the success of a program or questionnaire-type surveys that evaluate workers' beliefs and intents (and correlate with actual behaviors).

7.9 Rehabilitation

Noise and hearing conservation regulations fail to deal with the worker who has developed NIHL. This failure affects policies regarding hearing protector use when speech communication is necessary, the use of hearing aids by hearing-impaired workers in noisy areas, and the use of hearing aids with hearing protectors such as earmuffs. Thus the worker with acquired NIHL is often managed as a casualty who is no longer in the HLPP management system.

Management procedures for workers identified with substantial hearing impairment need to be studied. They would include training in listening strategies, speech reading, and optimal utilization of hearing aids. Research also needs to be directed at developing hearing instruments designed to help workers continue to function in noise while protecting hearing and enhancing communication.

Rehabilitation communication strategies need to be studied. Currently, if hearing-loss-prevention service providers were to suggest that noise-exposed workers with NIHL could benefit from amplification, they would be fired. In such a hostile environment, it is very difficult to define, develop, deliver, and evaluate a rehabilitation program.

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